DEVELOPMENT AND CHALLENGES OF ANEROBIC DIGESTION APPLICATION IN WASTEWATER TREATMENT.

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Abstract

There has been an increasing interest in the application of anaerobic digestion for the treatment of industrial wastewater. This is due to the recent advances in bioscience and biochemical process engineering. This paper outlines the potential beneficial aspects of the anaerobic process for methane production from industrial wastes and describes some recent developments in anaerobic digestion technology. Discussion on the environmental factors effecting the process is also included.

Introduction

Anaerobic treatment is the use of biological processes in the absence of oxygen for stabilization of organic materials by conversion to methane and inorganic end product including carbon dioxide and ammonia (1). As early as in the eighteen century, formation of methane from anaerobic decomposition of organic deposits was known .In the middle of the nineteenth century the involvement of bacteria in this decompsition became clearer. However, it was just one century ago (in 1881) when anaerobic treatment was reported to be a useful method for reducing the mass and putrescible nature of suspended organic material removed from municipal wastewaters. Since then, the applications of anaerobic treatment have grown steadily.

In recent years, anaerobic treatment has been accepted as an effective means of treating industrial wastewater (2). The industrial wastewater is compose of a complex mixture of chemical whose behaviour towards biological system can be very varied. Under the present legislation, industrial effluents may be discharge either to the sewage system or to natural water course, provided they conform to the requirements of the appropriate statutory bodies. The complex constituents of the industrial effluents will effect the biological treatment processes and the receiving water system. Treatment of these wastes is therefore of paramount importance.

Environmental Requirements of Anaerobic Digestion

In order to achieve the desired result in the anaerobic wastewater treatment, the environmental requirements of the different microorganisms cooperating in the methane process must be fulfilled. There are four important parameters which influence the anaerobic process.

1) **Nutrient requirements**

a) Nitrogen and Phosphorus.

The nitrogen requirement for anaerobic treatment is only a small fraction of that required by aerobic process and the phosphorus requirement is approximately 15% of nitrogen requirement.

b) Trace nutrient requirements.

The lack of understanding of trace nutrients requirements of methanogens has been a serious hindrance to the comercialization of anaerobic biotechnology. The lacking of trace nutrients was the cause of negative results in many anaerobic treatment studies of industrial wastewater.

Four elements-iron, cobalt, nickle, and sulfide have been shown to be essential for methanogens to convert acetate to methane.

The iron and cobalt requirements of methanogens were reported 20 years ago, but the difficulty of providing adequate iron in solution was not recognized. Thus, this is still a problem.

Recently, it has become known that specific cobalt supplementation averted a progressive process failure in an industrial waste water anaerobic treatment process.

The nickle requirement of methanogens is one of their distinct features,since nickle is generally not essential for the growth of bacteria. The nickle required was supplied as a contaminant in other mineral salts and in yeast extract,as well as from contact with stainless steel fittings and syringe needles. An adequate supply of nickle however, should not be assumed because it may be precipitated as a sulfide, and thus not be available in solution for bacteria nutrition.

Many industrial wastewaters are not nutritionally balance and often lacking in nitrogen, phosphate and trace elements. In such cases it is necessary to add components in sufficient amounts to the wastewater before treatment.

However the nutrient requirements of the anaerobic bacteria are much lower than of the aerobic ones since only a small amount bacteria biomass is formed. Requirements for nitrogen and phosphorus in anaerobic treatment processes were calculated and determine to be in the Carbon:Nitrogen:Phosphorus ratio of 700:5:1.

2) **Toxicity**

Methanogens are commonly considered to be the most sensitive to toxicity of all the microorganisms in the overall consortium for anaerobic conversion of organic to methane.

Since it would be rare to find an industrial wastewater which is completely devoid of all potential toxicants, there is a common belief that anaerobic biotechnology is not appropriate for treatment of most industrial wastewaters. This assumption has greatly hindered widespread application of the process to industrial wastewater treatment. Some of the toxicants encountered in specific industrial wastewaters are:

a) heavy-metals catalyst from chemical process.
b) pharmaceuticals (eg. monensin) added to animals feeds.
c) detergents and disinfectants used in food equipment cleanup.
d) Solvents from degreasing operations.
e) Inhibitors formed as secondary products (eg. cynide in coking operations)

However, anaerobic bacteria like most microorganisms can tolerate a wide variety of toxicants and even biograde some of them.

3) **pH and Alkalinity Requirements**

The optimum pH for methane fermentation is between 7 and 8, but the methane bacterio generally are not hramed unless the pH drops below about 6.0, the lower the pH the shorter the time for a given decrease in activity. For this reason, it is essential that the pH be maintained above 6 at all times. When the bicarbonate alkalinity drops below about 500 mg/l, and with the normal percentage of carbon dioxide in the digester gas, the pH will drop dangerously close to 6.0. When digesters become unbalanced, the volataile acid concentration increases, destroying the bicarbonate alkalinity.

Many industrial wastewater do not have organic nitrogen containing compounds and so alkalinity may need to be added to maintain a satisfactory level pH. This could be one of the most costly items in the treatment industrial wastes by anaerobic processes and should be investigated.

4) **Temperature:**

Temperature is an important enviromental parameter in anaerobic fermentation processes. Faster feormentation rates, faster solid-liquid seperation and minimization of bacterial and viral pathogens are some benefits of high temperature fermentation. Pfeffer (1974) used shredded municipal refuse to establish two optimum temperatures. The optimum in the mesophilic and thermophilic ranges were 42^{O}C and 62^{O}C, respectively. He also concluded that it was less expensive to produce CH_4 at the higher temperature. A definite aeclimataion period was required to initiate thermophilic fermentation.

The Benifits Of Anaerobic Digestion For Treatment Industrial Wastewaters (3,5).

The anaerobic method of treating industrial wastewaters offers a number of significant advantages over the aerobic method. The major factors for comparison are:

a) **Environmentally acceptable.**

The process, by its very nature, is totally enclosed and does not produce any environmental nuisance such as offensive odours and bacterial aerosols.

b) **Methane gas production**

Removal of organic material occurs by microbial conversion first to hydrogen, carbon dioxide and acetic acid, which then act as precursors to the final by products of methane and carbon dioxide. Hence it is largely in this last step, through the production of methane and carbon dioxide that the majority of the carbon oxygen demand (COD) is removed from the raw effluent. Thus gas production and COD removal are inextricably linked in the anaerobic treatment plant.

Due to a very long solids retention time and consequent low growth rate, the cell yield (i.e. solids production) is also extremely low, thus most of the carbon in the raw waste is available for methanogenesis and under normal circumstances the yield of methane would, on average, be 0.33 - 0.36 meter cubic per kilogram COD.

Biogas ignites at approximately 690^{O}C compared with 645 ^{O}C for natural gas and burns with a flame speed of approiximately 43 m/s. Under these circumstances, most equipments fitted for natural gas can be operated with biogas after suitable modification. The production of biogas is generally in excess of that needed to operate the anaerobic treatment system, and can be utilised to generate power for other on-site services. Hence, anaerobic digestion is an energy producing process rather than one that demands regular input of energy.

The net operating cost differential between anaerobic and aerobic treatment is approximately US$160 per metric ton less for the anaerobic process (assuming US\$0.06/Kwh, US\$4.50/10^6 Btu for disposal costs) (3). This cost differential may be as high as US\$250 for some milling and pharmaceuticals plants have potential of producing in excess of US\$500,000/Year of methane from anaerobic treatment of the industrial wastewaters.

However, the value of the methane rarely becomes the sole justification for selecting anerobic biotechnology. Rather, the reduced cost of excess cell disposal or reduced electricity consumption are the contributing factor favouring adoption anaerobic biotechnolgy.

c) **Response to factory operations.**

The response of the process to stop-start factory operations is important for two reasons :

a) The effluent treatment capacity will not be affected.
b) In order that financial benefit be gained from the gas produced.

The anaerobic process generally has been shown to have the ability to operate successfully under part day loading (i.e. 12 hours per day) and 5 days per week and has also been able to withstand complete shutdown for several months.

The gas production profile resulting from stop-start operation is, again, a common feature of most anaerobic processes . Although anaerobic bacteria have relatively low growth rate, this must not be confused with their substrate utilization rate. The high rate of substrate utilization is reflected in the response of gas production to load variations. In the case of soluble substrates a sudden increase in load is reflected proportionally by an increase in gas production generally within 15 minutes. Active anaerobic biomass can be preserved unfed for several months and this capability is important when treating wastewater from seasonal industries.

Anaerobic Treatment Systems (3,2).

The microbial biomass responsible for anaerobic biotechnology can be 'packaged' in variety of process configurations. Selection of the appropriate process configuration is critical to succesful operation and warrants detailed consideration. Each different configuration has implications for the ratio of solids retention time/hydraulic retention time (SRT/HRT). SRT is the fundamental design parameter of process stability and minimal sludge production. Minimal HRT minimizes the reactor volume and thus reduces capital costs.

a) Conventional digestion tanks

The first generation of reactors for anaerobic biotechnology applied to municipal sludge digesters consisted of continuosly stirred tank reactors which no solids recycle. Therefore, the SRT/HRT ratio was one.

b) Anaerobic contact process

Solids recycling was incorporated to increase the SRT/HRT ratio; this modification was termed the Anaerobic Contact Process. The process has been developed for the treatment of wastewaters from food and bioindustries. The first major class of industrial wastewaters employing the anaerobic contact process was meat-packing plant wastewaters.

This plant consists of a reaction tank followed by a settling tank (clarifier). The wastewater is treated in a continuosly stirred tank reactor with an active population of flocculated bacteria degrading the organic material into methane and carbon dioxide. The effluent passes through a sludge settler where the flocculated bacteria settle to the bottom and are then returned to the reaction tank. Because the bacteria are retained and recycled, this type of plant can treat medium strength wastewater (2000 - 20,000 COD mg/l), very efficiently at high hydraulic loading rates.

A major difficulty encounted with this processes is the poor settling properties of anaerobic biomass from biogas an the gas bubbles tend to adhere to the bacteria flocs. In order to overcome the poor sedimentation problem the following methods have been and recommended: Chemical flocculation, air stripping, flotation or centrifugation.

c) **Immobilized cell reactors:**

Process stability and economics dictate increased SRT/HRT ratios. Immobilized cell reactors are a rational attempt to achive these higher ratios. Many scheme have envolved. Coutler Et al (1957) and Young and Mc Carty (1969) used upflow packed column. The packing material provided contact surface for biofilm development, reduced the Reynolds number to ensure low turbulance and efficient sedimentation, and thus allowed the retention of unattached biomass.

The first prototype anaerobic filter in the United State was an uplow packed reactor, which treated a wheat starch wastewater. It was located at Centinial Mills in Spokane. In the uplow packed recator, a less than half of the cell mass is attached to the packing as a biofilm; the majority is unattach as clumps of cells retained in the packing interstices.

The concept of a downflow mode through a packed reactor was developed by Van Den Berg and Lentz (1979) to prevent accumulation of refractory particulates containing in the feedstock. The cell inventory is all in the biofilm attached to the packing. Any biofilm sludge particulates in the effluent. Either the submerged or unsubmerged protein is available with the downflw mode. Gas stripping of vlatile toxicants (eg H_2S) is enhanced in the downflow mode because all of the gas produced passes through the influent wastewater.

The fluidized bed developed by Jeris (1982) incorporates an upflow reactor partly filled with sand. The upflow velocity is sufficient to fluidize the sand to fill about 75 % of the reactor. A very large surface area is provided by the sand, and a uniform biofilm develops on each sand grain. The internal sand grain markedly increases the net density and settling velocity of the attached biofilm and ensures efficient cell retention within the reactor. The system readily allows passage of refractory particulates that could plugs packed bed, but requires energy for fluidization of the sand. A lower-density carrier, such as anthracite or high-density plastics heads, can be substituted for sand to reduce the fluidization energy requirements. Jewell (1982) has developed an expanded bed reactor that uses an upflow velocity less than that required for complete fluidizatin of the granule media.

The expense of the reactor packing material is considerable. Mc Dermatt (1983) estimates the packing costs is comparable to the tank cost. It may be on the order of US$ 350/m^3 for a large prototype system. In additin, concern over long-term plugging problems has fostered the development of unpacked reactors that still incorporate the immobilized cell feature.

Lettinga et al (1980) initiated the development of the first full-scale installation of an upflow anaerobic sludge blanket reactor (UASB) at the Central Sugar Manufacturing plant in the Netherlands. His laboratory studies have shown that he could develop a grannular sludge on beet sugar wastewater with excellent characteristics in an unpacked reator. He also demonstrated that exceptionally high loading rates of up to 30kg/m^3 could be applied. The mechanism by which the granular sludge is developed is not well understood , nor is the phenomenon responsible for its rapid disintergration under same conditions .

Recently, McCarty (1982) introduced a modification of the UASB called the baffled reactor provides staging, enhances cell retention, and avoids the cost packing material. Another modification of the process has been developed in France for sugar manufacturing and distillery wastewaters by the IRIS (Research Institute for Sugar Industry). The process combines a sludge bed and anaerobic contact process with an incorporated settler.

Conclusion

The future of anaerobic biotechnolgy for application in industrial wastewater treatment is promising. There is a well balanced effort in the areas of basic microbiology, bench and pilot plant studies, and full-scale installation. The major obstacle to wider application of the anaerobic process for industrial wastewater treatment are the relative difficulty in operation and the absence of a simple and cost-effective design.

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